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Assessing multi-level drivers of adaptation to climate variability and water insecurity in smallholder irrigation systems

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ABSTRACT

Smallholder agriculturalists employ a range of strategies to adapt to climate variability. These adaptive strategies include decisions to plant different seed varieties, changes to the array of cultivated crops, and shifts in planting dates. Smallholder access to irrigation water is crucial to the adoption of such strategies, and uncertainty of water availability may prove to be a stimulating force in a smallholder's decision to adjust their on-farm practices. Within smallholder irrigation systems, attributes at multiple levels influence water availability and collective action, and in the process play a role in adaptation: community-level governance institutions may influence trust in others and the ability to overcome appropriation and provisioning dilemmas, and, at the household-level, the availability of irrigation water and socioeconomic and demographic factors may influence farmer willingness to take on the risk of altering their on-farm practices. In this study we investigate smallholder adaptation in Kenya from multiple levels. Specifically, we identify the role of household- and community-level characteristics in shaping smallholder experimentation with different seed varieties. Standard ordinary least squares and logistic regressions are constructed to assess the influence of these interactions on smallholder adaptation. We further discuss the ability of smallholders to respond to poor water provisioning. Among the study's findings is evidence that smallholders are more willing to employ adaptive measures if they have a limited capacity to irrigate.

1. Introduction

Climatic conditions play a significant role in food security in semi-arid environments where livelihood is dependent on agriculture. Smallholders employ a range of adaptation strategies to mitigate the effects of changing climatic conditions, including seeking wage labor, diversifying livelihood practices, selling livestock, and, most relevant for this paper, changing the seed varieties that they cultivate. Given smallholders' economic vulnerability in the face of climate change, it is crucial to understand why some smallholders adopt adaptation strategies to minimize their risk and others do not. While a growing number of studies identify the drivers of smallholder adaptation strategies, most of the literature to date has focused on identifying the household attributes that explain smallholder adaptation behaviors (e.g., Hassan and Nhemachena, 2008; Bryan, Deressa, Gbetibouo, & Ringler, 2009; Deressa, Hassan, & Ringler, 2011; Kristjanson et al., 2012). In the present text, we argue that such studies have overlooked the potential importance of community-level variables, particularly attributes related to the resolution of collective action problems, i.e., problems where individual incentives differ from the incentives of the group. Our study, conducted in twenty-five community irrigation systems within a semi-arid region around Mount Kenya, approaches smallholder adaptation from multiple levels to identify

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attributes of the household and the community irrigation system that influence the likelihood of smallholders' use of adaptive strategies.

Reliable access to irrigation water has emerged as a key predictor of a households' use of adaptation strategies (Gower, Dell'Angelo, McCord, Caylor, & Evans, 2016). For example, Deressa, Hassan, Ringler, Alemu, and Yesuf (2009) found smallholders in Ethiopia's Nile Basin more willing to adapt to the effects of climate change if they had poor access to irrigation water. Likewise, in northern Ghana, farmers have responded to over-exploitation of groundwater for irrigation by adjusting their on-farm practices so as to cope with reoccurring water deficits (Laube, Schraven, & Awo, 2012). In both cases, the scarcity of water creates an incentive to adjust farming practices. However, smallholder adaptation cannot be understood by solely exploring household-level water availability, particularly where households share common irrigation systems. In semi-arid irrigation systems, trust that the collective group will coordinate their actions to ensure the functioning of irrigation infrastructure and that all smallholders will abide by water use restrictions is built on well-crafted water governance institutions capable of addressing collective action problems (Janssen, Anderies, Perez, & Yu, 2015; Lam, 1998; Ostrom, 1990). If members perceive that governance arrangements are insufficient to address these challenges, they may explore household-level adaptation strategies foreseeing the need to "go it alone" in the face of climate uncertainty (e.g., Markelova, Meinzen-Dick, Hellin, and Dohrn (2009) concerning market access). Studies such as Lam (1998) and Bardhan (2000) emphasize that effective management is key to smallholder water access; yet, to our knowledge research exploring the role of irrigation systems' institutional arrangements in shaping households' adaptive behaviors through the resolution of collective action dilemmas has been limited (some exceptions include Anderies, Janssen, Lee, & Wasserman, 2013; Janssen et al., 2015).

A substantial body of literature has been amassed to understand smallholder adaptation within settings of water scarcity and variable precipitation (e.g., Cooper et al., 2008; Deressa et al., 2009; Mertz, Mbow, Reenberg, & Diouf, 2009; Shiferaw, Okello, & Reddy, 2009; Below et al., 2012; Laube, Schraven, & Awo, 2012). Likewise, researchers have devoted much effort to understanding the role of institutional arrangements in resolving collective action challenges within irrigation systems (e.g., Ostrom, 1992; Ostrom and Gardner, 1993; Lam, 1998; Berkes, 2002; Ostrom, 2005; Huitema et al., 2009; Pahl-Wostl, Holtz, Kastens, & Knieper, 2010; Cox and Ross, 2011; Janssen et al., 2015). Surprisingly, these two lines of research have largely remained separate, and little attention has been given to the interplay between resource governance, water availability, and adaptation. For instance, studies such as Deressa et al. (2011) consider the role played by irrigation in allowing smallholders to adapt to climatic events; however, governance arrangements influencing the availability of irrigation water are largely overlooked. Conversely, studies such as Ostrom and Gardner (1993) and Lam (1998) give sufficient attention to the infrastructural and institutional drivers of smallholder water availability, and Ostrom (1990) has synthesized a set of "design principles" that are associated with reliable and sustainable water supplies. Yet, such studies rarely link governance to household-level adaptive behaviors.

The goal of this study, therefore, is to examine the degree to which institutional arrangements of irrigation systems (i.e., community-level attributes) and household-level elements, including irrigation water supply, affect smallholder adaptation. This study focuses on a semi-arid region near Mount Kenya where smallholder farmers receive water from community-based irrigation systems, known as Community Water Projects (CWPs). Consistent with previous research, we hypothesize that smallholder adaptation decisions depend on the reliability of irrigation water supplied by CWPs. In particular, we expect adaptation to occur when the supply of irrigation water to smallholders is less reliable (e.g., Deressa et al., 2009, 2011), holding constant other household attributes such as education and income level. We also hypothesize that CWP governance and attributes facilitating or inhibiting collective action matter. In particular, individual-level adaptation will be more likely when CWPs exhibit traits that have been found to inhibit collective action, such as within large CWPs or CWPs where members are less familiar with one another (Fujiie, Hayami, & Kikuchi, 2005; Ostrom, 2005). In both cases, we hypothesize that limited familiarity and trust for one another dispels confidence in the CWP's water provisioning mission and in turn leads smallholders to embrace their own endogenous adaptation strategies. Additionally, we hypothesize that smallholders residing within irrigation systems that have failed to adopt rules consistent with Ostrom's design principles – described below – will be more likely to employ adaptation strategies due to their own calculation of institutional failure in the face of climate variability.

2. Theory

2.1. Adaptation

The concept of adaptation has been analyzed in anthropology, sociology, and geography literatures, among others, for some time (e.g., Parsons, 1964; Grossman, 1977; Moran, 1991). In geography, for example, these were often studies of "man-land" or "man-environment" relations seeking to understand human adaptation made in response to changes in the physical environment (White, 1973). With the growing recognition of challenges posed by climate change, as well as the formation of scientific bodies such as the Intergovernmental Panel on Climate Change (IPCC), an uptick in climate change adaptation research has taken place represented by the publishing of thousands of climate change articles each year and the creation of new scholarly journals devoted to gaining a deeper understanding of the issue (Berrang-Ford, Ford, & Paterson, 2011; Hulme, 2010).

Along with providing a better understanding of individual-, community-, and national-level responses to changing conditions, the swell of climate change adaptation research has encouraged deeper inspections of what truly should be considered "adaptation." For instance, Perramond (2007) emphasized a need to account for the temporal dimension of adaptation. He suggested using the term "adaptation" for changes that were certain to be long-term, such as the movement of a group of sedentary farmers to an area more favorable for cultivation, while "adaptive tactics" would consist of fleeting adjustments and "adaptive strategies" would consist of those tactics that, over time, materialize into a more systematic strategy. The IPCC has offered a more widely-recognized definition for the term "adaptation", which they describe as "the process of adjustment to actual or expected climate and its effects" (Field et al., 2014: 40). While this definition does not explicitly address the issue of temporal duration (i.e., the difference between a fleeting alteration and a long-term change), it does suggest that adaptation can occur either *ex-ante* or *ex-post*. Throughout this article, our usage of "adaptation" is consistent with the somewhat broader definition provided by the IPCC.

However, adding some nuance to the IPCC definition, we follow Tschakert and Dietrich (2010) in advocating that adaptation be viewed as encompassing a learning process in which adjustments develop over time. In other words, climate adaptation is not a linear process; rather, it is intermittent and varied as individuals navigate their own incomplete information concerning climate change

(van Aalst, Cannon, & Burton, 2008). Experimentation is an important part of this intermittent and irregular adaptation process as individuals and groups learn through their own actions and discover strategies most effective for their particular settings. In our analysis of adaptation in the Mount Kenya region, we assess smallholder experimentation with seed varieties as a form of on-farm adaptation; in the process, we acknowledge that adaptation is frequently an iterative process of trial-and-error.

2.2. Seed choice as adaptation

Seed experimentation is the primary adaptation strategy explored herein. Changing seed varieties is a common adaptive strategy employed by smallholders to cope with external shocks (Burnham and Ma, 2015; Harmer and Rahman, 2014). For instance, changing to an early or intermediate maturing maize variety helps farmers adjust to new climatic regimes in which precipitation events are increasingly difficult to predict (Osbahr, Twyman, Adger, & Thomas, 2008; Waldman, Blekking, Attari, & Evans, 2017). In a survey of Kenyan farmers, Bryan et al. (2013) found that shifting to early maturing varieties was the primary adaptive strategy employed by smallholders confronted by temperature and rainfall change. Similarly, an analysis of Ethiopian smallholders found that the decision to plant new seed varieties was a dominant adaptation strategy and that factors such as household size, education levels, and exposure to extension services influenced whether this strategy was employed (Deressa et al., 2011).

Essentially, by experimenting with different seed varieties, farmers are either adjusting their farm management strategies to match an abbreviated rainy season, or they are intending to reduce their exposure to variability in rain events during the growing season. In some instances, farmers will plant short, intermediate, and late maturing varieties in the same field so that, if an extended rain season does not fail, they are able to harvest their late duration varieties, which typically have higher yields, but if the rains do fail, the farmer may at the very least be able to get their short duration seeds to maturity (Ogalleh, Vogl, Eitzinger, & Hauser, 2012). Experimenting with new seed varieties does, however, require a willingness of a farmer to take on risk (Feder, Just, & Zilberman, 1985; Rogers, 1995). We rely on findings from studies such as Ghadim and Pannell (1999) and Knowler and Bradshaw (2007) – which both inspected farm-level adoption of new cultivation practices and the drivers of such adoption – to aid in predicting willingness to experiment with different seed varieties. In general, we expect that farmers better positioned to shoulder increased risk (i.e., younger, wealthier, better educated) will be the same individuals that are more willing to try a different seed variety.

2.3. Collective action and resource governance

Household willingness to experiment with on-farm techniques may also be a product of community-level resource management strategies (Cosens and Williams, 2012). In irrigation systems, individual group members' interests may differ from group incentives, such that reliable water supplies depend upon effective governance strategies. In irrigation systems, decision-makers are in the unique position of needing to craft water management rules to solve two collective action problems (Cox and Ross, 2011; Janssen, Anderies, & Cardenas, 2011). The first is a provisioning problem: the group must establish and maintain the irrigation system's physical infrastructure, despite individuals' incentive to free-ride and benefit from the labor of others while providing no inputs themselves. The second is an appropriation problem, which relates to individual excessive water consumption that, in turn, reduces available water to other users. Appropriation problems are common within upstream-downstream environments since those with first access to water may be indifferent to, or unaware of, downstream water demand. If left unattended, these dilemmas can reinforce water inequalities within irrigation systems: as members of the irrigation system learn of inequalities, those receiving less water grow increasingly unwilling to invest in the infrastructural and management solutions to overcome collective action obstacles (Perez, Janssen, & Anderies, 2016).

Certain conditions pose substantial challenges to irrigation systems in their efforts to overcome collective action obstacles. For example, group size and service area could impinge on collective efforts since transaction costs associated with coordination increase with additional members and limited exposure to one another (Hardin, 1982). Irrigation systems with large service areas may experience limited communication among members, and Janssen et al. (2011) and Janssen et al. (2015) both demonstrated greater water inequalities between upstream and downstream members where communication was limited, furthering collective action challenges. A group of heterogeneous rather than homogenous water users may also struggle to act collectively if distrust, which is expected to be higher within a heterogeneous group, interferes with ability to establish and abide by agreements (Walker and Ostrom, 2009). Additionally, origin of the user group and income disparities have been shown to influence collective-action, with members of older user groups showing more cooperation (Fujiie et al., 2005) and user groups with greater income disparity showing less cooperation (Ternstrom, 2003).

Whatever the conditions of the user group may be, institutional arrangements may be developed to reduce uncertainty in complex environments. Ostrom (1990) formulated eight general design principles characterizing multiple rule types thought to facilitate trust and norms of reciprocity within user groups. By fostering such values across the user group membership, an irrigation system may be more likely to overcome collective actions dilemmas if water management strategies clearly reflect these principles. Thus, Ostrom's design principles are commonly used to theorize about a user group's long-term likelihood for success or failure. These design principles include the following: (1) clearly defined geographic and membership boundaries; (2) congruence between appropriation and provision rules and local conditions; (3) provisions that the individuals affected by the rules-in-use are also able to participate in modifying these rules; (4) presence of monitors to assess rule compliance; (5) presence of graduated sanctions where severity of punishment increases with severity of offense; (6) access to conflict-resolution arenas; (7) minimal recognition by outside governmental authorities of members' rights to devise their own institutions; and (8) nesting of governance operations, including appropriation, provision, and monitoring activities, within increasingly larger governmental jurisdictions. Given the need for resource management to resolve collective action dilemmas, our statistical analysis, which we describe below, includes explanatory variables approximating several design principles.

3. Water governance and the Mount Kenya region: describing the study area

Growing tensions between water users with conflicting interests (e.g., commercial versus subsistence farmers) and farmers at competing geographic locations (e.g., upstream versus downstream smallholders) contributed to a realignment of Kenya's water institutions in 2002 from top-down to polycentric water governance (Baldwin, Washington-Ottombre, Dell'Angelo, Cole, & Evans, 2016). With the 2002 Water Act, the Water Resources Management Authority (WRMA) was established to devise policy and issue permits at the regional level and, at the catchment level, Water Resource Users Associations (WRUAs) were set up to coordi-

nate water use and resolve conflicts between upstream and downstream water users (WRMA and WSTF, 2009). This multilevel structure bears characteristics of an adaptive management system (Dell'Angelo et al., 2014). For instance, coordination mechanisms are in place that allow the WRUA and WRMA to collectively establish water sharing procedures during times of scarcity (McCord, Dell'Angelo, Baldwin, & Evans, 2016).

Within each WRUA are multiple Community Water Projects (CWPs) – communities with shared water distribution infrastructure and management strategies. CWPs coordinate with their WRUAs through representatives from each of the communities within a particular catchment who serve on the WRUA's management board (Dell'Angelo et al., 2016). During the dry season, coordination between CWPs and their respective WRUAs becomes particularly important. A WRUA is responsible for instituting dry season water rotations between all member groups of the same catchment, including CWPs (WRMA and WSTF, 2009). These rotations designate which CWPs are allowed to have their intakes open on particular days. While these dry season rotations are in place, WRUA personnel patrol riparian zones to ensure that all member groups who are not scheduled to receive water honor the agreed upon rotation and keep their intakes closed. Aside from making decisions as to when and how to structure dry season water rotations, the WRUA management committee works with CWPs to resolve disputes between communities arising over illegal water use activities.

Within the Mount Kenya region, we focus on twenty-five CWPs on the northern and northwestern slopes of the mountain, each of which is positioned within a WRUA (Fig. 1). The study area is biophysically dynamic as precipitation rapidly decreases moving from atop Mount Kenya to the northwestern reaches of the study area. Livelihood strategies typically center around sedentary farming practices within the CWPs nearest the mountain where precipitation levels are highest. Pastoralism is more common in the downstream communities where precipitation levels are lowest (McCord, Cox, Schmitt-Harsh, & Evans, 2015). Farming operations within the study area are primarily rain-fed, but irrigation water provided by a household's CWP is used to extend growing seasons and mitigate the effects of dry spells (Ericksen et al., 2011). Concerns about river water sustainability have been fueled by consistently diminishing streamflow within the region's major rivers since the 1960s, a period coinciding with rapid in-migration of farmers to the study area (Liniger, Gikonyo, Kiteme, & Wiesmann, 2005; Ngigi, Savenije, & Gichuki, 2007).

Each CWP has an intake pipe abstracting water from one of the area's major rivers. After water is withdrawn, it is gravity-fed through a series of polyvinyl chloride pipes to CWP households (Fig. 2). Water provided through the CWP can be used for household consumption and irrigation, although during particularly dry periods when water is rationed in all CWPs smallholders are instructed not to irrigate. In some cases, a large tank or reservoir is used to hold and ration water before it is distributed to households.

The infrastructural traits of the CWPs vary across the studied communities. For instance, pipe networks range in age with the oldest CWP forming in the early 1970s while the newest was established in 2008. The size of the pipe networks varies as well. Some communities feature an expansive pipe network with total pipe length exceeding 30 km, while in other communities the distribution lines total less than 1 km. Total pipe length corresponds with the service area of communities: the most expansive CWP covers an area of 57.6 km^2, while the smallest is less than 1 km^2.

From an institutional standpoint, CWPs employ a range of management strategies in an effort to supply all members with equitable amounts of water. For example, limitations may be placed on the number of members allowed into the CWP (which is true in eight out of the twenty-five communities examined in this paper). Rationing strategies are also common, and year-round water rotations between CWP members may be enforced, in which households only receive water on certain days of the week (fifteen out of twenty-five CWPs; these rotations are not to be confused with the WRUA-imposed rotations). In many cases, a CWP rotation will indicate that each household is to get water every other day or every third day during the week. Rotations that are enforced throughout the entire year are often spurred by the need to responsibly distribute water among a particularly large membership. Water managers will also impose a host of sanctioning strategies in order to discourage misuse of water, including monetary fines for illegally tampering with water distribution pipes. Additionally, CWPs differ in their rules designating responsibilities for maintaining pipe infrastructure, criteria to become a CWP member (such as the financial cost of membership and the number of conditions to be met to become a member), and member monitoring obligations.

The individuals responsible for crafting these rules are elected by the membership to serve on the CWP's management committee. Management committees typically comprise representatives from each of the major lines or population centers within the CWP. For example, a CWP with five major lines may have a management board that consists of three representatives from each of the major lines, creating a management committee of fifteen individuals. From these fifteen individuals a chairperson, treasurer, and secretary (and in some cases, a vice-chairperson and vice-secretary) are selected for the executive committee. Those representatives who are not selected for the executive committee continue to serve on the management board and help to ensure that households from all parts of the CWP are represented. In so doing, individual households are given an opportunity to participate in rule modification, albeit indirectly through their representatives. Term lengths for management committee personnel vary by CWP, with the majority of CWPs reporting a term length of two years. Protocols on re-elections also vary: some CWPs allow all members to seek re-election indefinitely, while others strictly limit service to two years or, at the very least, require a brief hiatus before returning to the management committee.

4. Methods

4.1. Hypotheses

The goal of this paper is to understand smallholder adaptation within irrigation systems with respect to both household- and community-level characteristics. At the household level, we are primarily interested in the role played by irrigation water in adjusting on-farm practices given the importance of irrigation in bridging unexpected dry periods and extending growing seasons (Below et al., 2012; Rockstrom et al., 2010). We are also interested in identifying how other household-level traits, such as income and exposure to extension agents, influence farmer experimentation. At the community level, we are interested in how institutional arrangements and user group traits, such as group size and membership familiarity with one another, shape household-level adaptation. We believe that smallholder adaptation will take place when user groups are unable to overcome collective action dilemmas since households respond to persistent provisioning and appropriation failures through individual on-farm adjustments.

Table 1 hypothesizes the influence that household- and community-level characteristics will have on smallholder adoption of seed varieties. We include each of these as explanatory variables in logistic regression models that we use to understand smallholder adaptation.

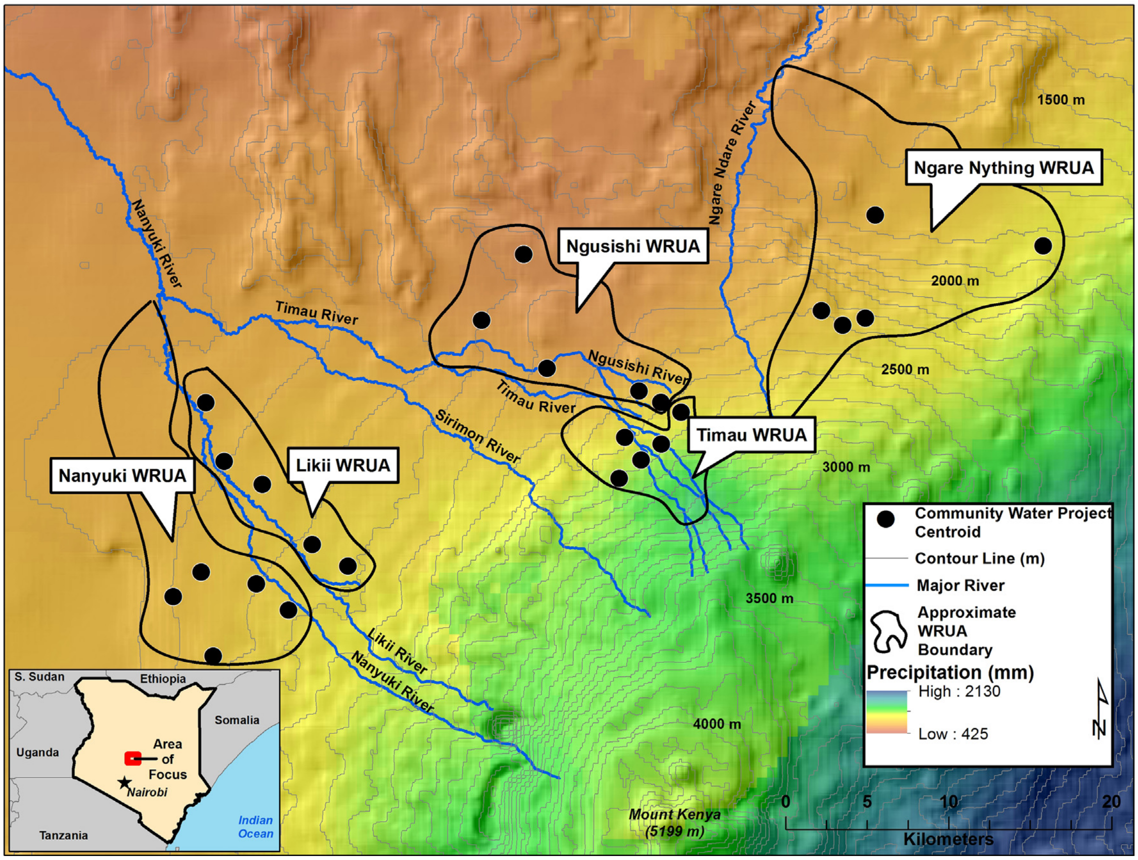

Fig. 1. Study area.

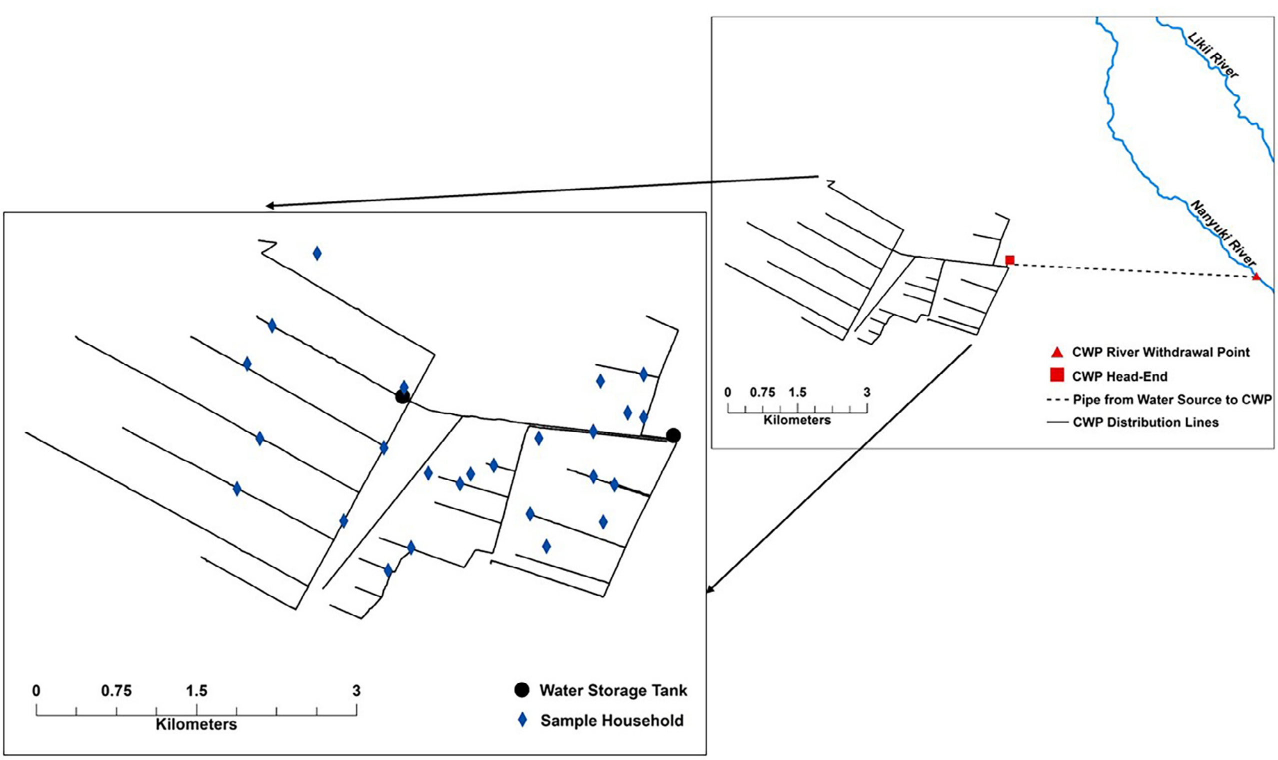

Fig. 2. Configuration of a CWP. The layout of a CWP is displayed here, with both the position along a river (right) and the configuration of distribution lines (left) given.

Table 1
Hypothesized relationships.

Variable	Hypothesized relationship with adoption of different seed variety	Explanation
Variability of irrigation water provided through CWP	+	In this study we use the coefficient of variation of CWP water delivery to measure reliability of household water supply. Increasing irregularities in water supply provide an incentive for smallholders to adjust their on-farm practices (Deressa et al., 2009, 2011). As it relates to seed choice, farmers will experiment with varieties capable of reaching maturity during wet seasons, since a successful harvest is less contingent on the ability to irrigate
Total income	+	Adoption of new cropping strategies requires financial security to mitigate against a failed endeavor (Somda et al., 2002)
Age of household head	–	Willingness to take new risks, such as using a new seed variety, may decrease with age (Clay, Reardon, & Kangasniemi, 1998)
Education level of household head	+	Education exposes farmers to new ideas and reduces their aversion to take on risks (Knight et al., 2003; Rahm and Huffman, 1984)
Number of extension meetings attended	+	Exposure to new ideas and technical support will increase farmer willingness to trial new on-farm techniques (Rahm and Huffman, 1984)
Importance of livestock income	+	A diversified income reduces the risk of a failed new endeavor (Somda et al., 2002)
Total household members	+	A large, readily available labor pool provides an opportunity for the farm to experiment with new cropping techniques (Ghadim and Pannell, 1999)
Age of water project	–	A long-established CWP where members have experience overcoming collective action dilemmas will foster trust among the membership (Fujiie et al., 2005). Smallholders do not sense a need to adjust farming practices due to confidence in the governance regime to carry out its core responsibilities of water provisioning
Whether CWP expanded in past 5 years	+	Collective action will be more difficult to achieve in larger groups where individuals have not had an opportunity (or enough time) to forge trust in each other (Fujiie et al., 2005; Janssen et al., 2015). Concerns of provisioning and appropriation failures may arise from distrust in other members and, in turn, fuel household willingness to experiment with their own adaptation approaches
CWP rotates water to members during the wet season	+	The need to rotate water between members during the wet season is consistent with large user group size. Large memberships create coordination and organizational challenges capable of disrupting water delivery and collective action (Hardin, 1982). Smallholder adaptation will take place if governance failures result in irregular water delivery
Area of water project	+	Expansive water distribution networks where member interactions are limited will challenge the formation of trust (Anderies et al., 2013; Janssen et al., 2015). In turn, smallholders will be more likely to experiment with different seed varieties if they doubt the willingness of other members to collectively overcome provisioning and appropriation dilemmas
Total number of penalties for tampering with water distribution pipes	–	Lam (1998) demonstrated that irrigation systems with a larger number of sanctioning arrangements in place had better maintained infrastructure as they were able to overcome provisioning dilemmas. Ostrom (1990) found user groups with increasingly severe penalties for infractions to be better able to overcome collective action challenges. We hypothesize that CWPs with graduated sanctions in place improves member ability to overcome collective action challenges and breeds confidence in the water governance regime. Confidence in a CWP's ability to overcome collective action reduces the need to adjust on-farm practices
Total number of membership rules	–	More stringent membership requirements, represented by a greater number of eligibility rules, is indicative of a CWP preselecting for individuals that are willing to comply with rules and care for pipe infrastructure (Lam, 1998; Ostrom, 2005). This will produce a membership base with a strong social norm for collective action. As members gain trust in one another and confidence in their governance arrangements and water delivery infrastructure, they find a reduced need to employ individual adaptation strategies (such as experimenting with a different seed type)

Note: Some elements of this table have been adapted from McCord et al. (2015).

At the household level, we hypothesize that smallholders with more variable water delivery, and thus under more pressure to adjust farming practices to align with climatic and irrigation irregularities, will be more willing to adopt a different seed variety (Deressa et al., 2009). We include other household-level variables in our analysis – income, education, age of the household head, household size, the number of extension meetings attended in the past year, and the importance of livestock to the household's income – since these have been shown to affect smallholder adjustment of farming approaches (Feder, 1982; Feder, Just, & Zilberman, 1985; Knowler and Bradshaw, 2007; Rogers, 1995). The hypothesized relationships for these variables are influenced by the technology adoption literature, which indicates that wealthier, younger, and larger households may be less risk-averse and therefore more willing to experiment with, or adopt, different on-farm practices (e.g., Somda, Nianogo, Nassa, & Sanou, 2002; Knowler and Bradshaw, 2007), and that better educated households will consume more information about different on-farm strategies and are thus more likely to adopt new practices (e.g., Knight, Weir, & Woldehanna, 2003).

At the CWP level we include variables in our analysis that are consistent with an irrigation system's ability to resolve collection action dilemmas given that an inability to resolve these dilemmas may incentivize household adaptation. Lack of familiarity and failure to form strong social bonds among members may fuel disregard for other members and disinterest in overcoming labor provisioning and water appropriation dilemmas. As proxy indicators for member familiarity, we include four variables. Since geographical separation between members leads to limited interactions, we include the total area of the user group. We also include the presence of a rotation schedule during the wet season, which is characteristic of CWPs with large memberships whose

members may lack familiarity with one another. Similarly, the age of the CWP and the presence of recently added members may also influence familiarity and trust across the membership (Anderies et al., 2013; Fujiie et al., 2005; Janssen et al., 2015). In particular, a CWP that has been long established will be better able to resolve collective action dilemmas since the membership has more previous experience overcoming these challenges to draw upon, and a CWP where new members have been added in the past five years will be more likely to struggle developing trust and, in turn, have less success resolving collective action dilemmas. Finally, we include two variables, the total number of penalties for tampering with CWP pipes and the total number of membership rules, that represent rule types capable of forming trust across the CWP membership. CWPs that impose more sanctions with increasing severity for tampering with CWP infrastructure meet one of Ostrom's design principles (i.e., graduated sanctions). Belief among the membership that rule violators will be held accountable for the severity of their actions breeds confidence in the robustness of the CWP as a whole. The total number of membership rules is similarly reflective of Ostrom's first design principle: the boundaries to membership are clearly defined. Thus, a CWP that imposes more restrictions on who may join and better defines the criteria for membership may produce a member base that is more engaged and better stewards of the water resource and irrigation infrastructure. We believe that both the presence of graduated sanctions and the clearly defined boundaries for membership improve CWP collective action and breed confidence in the water governance regime, which in turn assures smallholders of reliable water delivery and mitigates farmer need to adjust on-farm practices.

4.2. Data

Data collection was conducted within each of the twenty-five CWPs shown in Fig. 1. The chairpersons of the CWPs were introduced to our research project at a group meeting wherein the research objectives were explained to all chairpersons within the same WRUA. We then selected five water projects in each WRUA from those CWP chairpersons who were interested in participating in the research program. To the extent that it was possible, we selected CWPs that spanned an upstream-downstream range (see Fig. 1).

Two separate data collection efforts provide the household level information used in our analysis, one conducted in 2013 and a second conducted in 2014. In 2013, household surveys were administered to 750 smallholder farmers across the twenty-five CWPs. These surveys provided information on socioeconomic and demographic traits, agricultural practices, and water use strategies. A minimum of thirty surveys were conducted in CWPs with large memberships, while in CWPs with fewer than sixty members, our goal was to sample at least half of the membership. We targeted all major water distribution lines within each CWP and sought to administer surveys with households on the upper, middle, and lower segments of these lines in order to obtain sufficient geographical representation. Further, to avoid spatially clustered responses, every third household was visited along the distribution lines when possible (i.e., after concluding a survey with household A, we would proceed past households B and C before stopping at household D to conduct the next survey).

The 2014 household surveys were administered to a subset of the households visited in 2013 and focused on smallholder adaptation and experimentation practices, as well as questions concerning the seed varieties planted that season and the times of planting. This fieldwork campaign took place from May to August, the period typically referred to by farmers as the growing period for the "long rains" season. For the logistic regressions, which we describe below, we draw upon data derived from the households that were visited in both 2013 and 2014 (N = 207).

In addition to the household level information collected in 2013, a separate survey was administered to the chairpersons of each of the twenty-five CWPs. These surveys queried aspects of the CWP infrastructure and the rules-in-use for managing water. In particular, they detailed membership criteria, approaches for managing water during the dry season, the sanctioning procedures for misuse of water, strategies for monitoring water misuse, and general characteristics of the CWP, such as its total number of members and year of establishment.

The 2013 fieldwork effort also captured information on household-level water delivery by repeatedly visiting the same members within each of the CWPs on a weekly basis from June 2013 to January 2014 to provide a temporal record of water flow. In larger CWPs, twenty households were repeatedly visited each week, while in smaller CWPs, visits were made to ten households; a total of 370 households participated in this effort. We collected the flow rate approximately twenty-eight times per household over a seven month period. Like the household surveys, we conducted our assessments of water delivery at the upper, middle, and lower segments of the CWP, and we only went to households that were also participants in the 2013 household survey. Water delivery was measured by recording the duration of time needed to fill an 18-liter bucket, which was then used to calculate average household flow rate (in liters per minute) and the coefficient of variation of household water flow. Coefficient of variation (CV) is a measure of relative variability and is estimated as follows: CV = (standard deviation/mean) * 100. These data help to reveal households that are positioned on less efficient distribution lines, such as lines with leakages, as well as CWPs that have inherently poor or inequitable water delivery. To ensure that measurements could be compared across weeks, the buckets were always filled from the same household line after all other taps had been turned off. While 370 households were visited over the course of this data collection effort, we include only those households that were also respondents to both the 2013 and 2014 household surveys in the logistic regressions (N = 207).

Finally, we coded the bylaws and constitutions of the twenty-five CWPs to obtain information on election procedures and terms of service for those serving on the management committees. We anticipated characteristics such as term lengths and membership engagement with CWP issues, such as water misuse and damaged infrastructure, to influence water delivery. In coding the bylaws and constitutions, we focused on the presence (or absence) of the following content: the range of positions on the executive committee; the term limits of the executive committee positions, as well as the number of consecutive terms served by personnel; and whether the management committee is representative of its memberships, such as a committee made up of representatives of each of the CWP's primary distribution lines.

4.3. Description of statistical analyses

We explore smallholder adaptation by employing a set of logistic regressions to investigate the influence of household-level traits, including household capacity to irrigate (estimated using the coefficient of variation of water delivered by the CWP to the household), and CWP-level traits, representing ability to overcome appropriation and provisioning dilemmas, on smallholder adoption of different seed varieties. We explore experimentation with a different seed variety as a form of adaptation through survey questions designed to understand a) whether farmers planned to experiment with a different variety in the coming season and b)

whether farmers had experimented with a different maize seed variety in the past five years.

We also asked farmers to provide the name of the seed variety they experimented with. We then classified the seed varieties listed as early (75–120 days), intermediate (100–160 days), and late (150–210 day) maturing varieties based on definitions from seed companies and local experts. Varieties that were unrecognized or could not be classified were dropped. This information was then used to see if respondents who had adopted different seed varieties in the past, or who planned to change in the future, had switched to varieties with a shorter period to maturity. Next, we compared farmers' choices with their own assessments of recent rainfall events (i.e., whether precipitation was less than, equal to, or greater than what the farmer viewed to be the typical amount of rainfall) and we compared seed choice decisions with precipitation values from 2009 to 2014.

Precipitation data were provided through Climate Hazards Group InfraRed Precipitation with Station (CHIRPS) datasets (Funk et al., 2015). CHIRPS establishes gridded rainfall estimates using 0.05° resolution satellite images and data collected from rainfall stations. We use CHIRPS data from 2009 to 2014 to determine if decisions to adopt shorter maturity varieties have taken place in the most water-stressed locations within the Mount Kenya region, thus providing evidence that farmers' decisions to experiment with shorter maturity maize varieties are, in fact, adaptation strategies to cope with challenging climatic conditions. Precipitation values were assigned to the GPS location of all survey respondents. In investigating farmer intention to adopt a different seed variety in the next year, we rely on monthly CHIRPS data from the sowing period at the onset of the 2014 long rains season (i.e., March, April, and May 2014). We rely on monthly CHIRPS data throughout the sowing and growing periods for the previous five years (i.e., March to August for 2009, 2010, 2011, 2012, and 2013) when investigating farmers that expressed they had experimented with a different seed variety in the previous five years. A set of independent group t-tests were performed to determine if farmers that adopted (or were planning to adopt) shorter maturity varieties (i.e., early and intermediate seeds) had experienced different rainfall regimes than those that adopted longer duration varieties. These comparisons allow us to verify whether experimentation with new seed varieties does in fact appear to be a form of adaptation to precipitation conditions.

After demonstrating the connection between seed experimentation and adaptation, we looked at determinants of adaptation as described above (see Table 1). These determinants were estimated using a set of logistic regressions of the impact of household- and CWP-level characteristics on adaptation as follows:

$$Y_{ij} = \alpha_0 + \beta_1 H_i + \beta_2 I_j + \mathcal{E}_{ij} \tag{1}$$

where Y represents a binary variable indicating whether a farmer expected to try a different seed variety within the next year or their admission to having tried a different seed variety in the past five years, H is a vector of household-level traits including a variable for water availability, and I is a vector of CWP-level indicators of collective action. The standard errors were clustered by the CWP to account for the multilevel nature of the data. Clustering the standard errors at the CWP level also accounts for the geographical – and hence, rainfall – variation between the different locations. We estimated two separate logistic regressions – one for each of the outcome variables (i.e., whether a farmer anticipated trying a different seed variety within the next year *and* whether a farmer had tried a different seed variety in the past five years).

5. Results

5.1. Connecting seed experimentation to smallholder adaptation

We were interested in identifying whether smallholder adoption of a different seed variety was related to increasingly challenging climate conditions. Farmers who expressed that they would try a new seed variety in the future overwhelmingly indicated that the most recent sowing period (i.e., March, April, and May 2014) had been drier than previous sowing periods (as indicated by farmers stating that March, April, and May 2014 had either been *somewhat dryer than normal* or *much dryer than normal*). In fact, 88% of households that were considering adopting a different seed variety believed that the recent sowing period had been drier than normal, suggesting a desire to adopt a variety that reached maturity earlier and was thus less susceptible to drought.

Table 2 displays the number of farmers who indicated that they had or intended to experiment with different seed varieties by the seed maturity classification. Note that early and intermediate maturing varieties were grouped together due to the large number of seed varieties whose maturity periods overlapped. Table 2 indicates a preference for early and intermediate maturing varieties by those farmers who have experimented or intend to experiment with a different seed variety.

To determine if shorter maturity varieties were disproportionately adopted in more challenging environments, a set of independent group t-tests were performed. Households were grouped according to whether they experimented (or intended to experiment) with an early or intermediate maturing variety or if they experimented (or intended to experiment) with a late maturing variety. Monthly CHIRPS data represent the precipitation (reported in mm) for each household location. Looking at experimentation with a new variety in the next year, the results of the t-test suggest that rainfall is lower on average for the group intending to adopt shorter maturing varieties (mean = 92.43 mm, SD = 26.32 mm) compared to the group intending to adopt late maturing varieties (mean = 103.37 mm, SD = 22.51 mm); yet, the difference is not statistically significant ($t(45) = -1.5198$, $p = 0.1356$). On the other hand, as it relates to experimentation within the previous five years, the t-test indicates that rainfall was significantly lower for farmers adopting early and intermediate maturing varieties (mean = 67.98 mm, SD = 10.90 mm) compared to farmers adopting late maturing varieties (mean = 72.51 mm, SD = 12.55 mm); $t(185) = -2.6944$, $p = 0.0077$.

5.2. Adaptation, water flow, and governance

Next we examined the household-level and CWP-level variables that associate with intended seed adoption (Table 3). At the household level, a higher CV of water flow (greater relative variability) was positively correlated with a farmer's willingness to adopt a different seed variety in the next year, suggesting that greater variation in water flow is associated with a willingness to take adaptive measures. This implies that a smallholder's water security (and presumably perception of water security) has a bearing on the adaptive strategies that they employ. Household interaction with agricultural extension officers through meeting attendance is also associated with intended seed adoption, suggesting that farmers with more contact with agricultural extension officers are more likely to adopt a different variety in the future. At the community level, CWPs that enforce a larger swath of rules to guard against tampering with pipe infrastructure correlated positively with a willingness to change seed varieties. On the other hand, membership growth appeared to deter adaptation: CWPs that had increased their memberships in the previous five years were

Table 2
Survey responses of smallholders experimenting with seed varieties.

Anticipated/past seed adoption	Early or intermediate maturing varieties	Late maturing varieties
Smallholder survey responses indicating an intent to experiment with a different seed variety within the next year	25 (53.2%)	22 (46.8%)
Smallholder survey responses indicating experimentation with a different seed variety during the past five years	106 (56.7%)	81 (43.3%)

Notes: Percent of total responses shown in parentheses.

negatively associated with willingness to adopt a different seed variety.

In terms of past experimentation with different seed varieties, we also found that the CV of household water delivery (higher relative variability) was positively associated with seed variety experimentation, again demonstrating a relationship between adaptation and water security (Table 4). Also at the household level, total income had a small but positive association with past experimentation. At the community level, if a CWP rotated water to its membership during the growing season, a negative association existed with past seed variety experimentation. A negative relationship also existed between the total number of membership rules in place and past seed adoption. Alternatively, total area occupied by the CWP was positively correlated with past testing of seed varieties, and, similar to the results from the previous regression, the total number of penalties guarding against tampering with pipes was also positively associated with past seed experimentation.

6. Discussion

6.1. Explaining the water security-seed adoption linkage

As a critical input to semi-arid agriculture, access to irrigation water plays a significant role in farm level decisions. The logistic regressions found that unreliable irrigation water delivery from the CWP associated with seed experimentation. This finding confirms our initial hypothesis from Table 1 that the absence of a dependable supply of irrigation water will encourage experimentation as farmers seek varieties capable of reaching maturity during rainfall periods (and hence do not need to rely on irrigation to bring crops to maturity during dry periods). We explore this result in greater detail for both anticipated and past seed experimentation.

Deressa et al. (2009) found that decreasing precipitation led to increasing likelihood of smallholder adaptation. In their study, farmer strategies adjusted in an effort to maintain production in the face of adverse conditions. Similar responses to water availability appear to be taking place in the Mount Kenya region: smallholders with less predictable water delivery from the CWP are more likely to indicate their intention to experiment with a different seed variety in the future. Therefore, farmers may be signaling their realization that they have unreliable water delivery and do not view their irrigation capacity to be able to bridge a future dry period; thus, seed experimentation may be the most viable means of adapting to changing conditions. Our independent group t-test, while not finding a significant difference in rainfall between smallholders intending to adopt shorter maturing varieties and those intending to adopt late maturing varieties, also agrees with this supposition as rainfall was, on average, lower for the group of farmers that indicated a willingness to experiment with shorter maturing varieties. Thus, evidence exists that seed experimentation in these more challenging environments is performed to confront water insecurity.

Turning to previous seed adoption, recall decay bias – i.e., the inability to accurately recall events over time – deserves mentioning before exploring the results. Studies such as Bound, Brown, and Mathiowetz (2001) demonstrated that error is introduced to survey responses as time elapses; hence, some caution should be exercised when respondents have been asked to recall an event that has previously occurred. On the other hand, Beegle, Carletto, and Himelein (2012) claimed that events with greater salience are more likely to be remembered more accurately by smallholders. Because exposure to a different seed variety may be spurred by a notable dry period, may be accompanied with a financial transaction, or may have been the product of a conversation with an extension agent, or all three, we believe that past seed experimentation is a salient event that smallholders will recall, even if it occurred several years in the past.

Similar to anticipated seed adoption, less reliable water provisioning from the CWP associates with previous trialing of

Table 3
Logistic regression of the likelihood of future experimentation with a new seed variety and determinants.

Experiment with new seed variety in the future	Coef.	Std. Err	z	P > |z|
Coefficient of variation of water flow[HH]	3.187***	1.280	2.49	0.01
Total income[HH]	0.000	0.000	0.24	0.81
Age of household head[HH]	0.001	0.014	0.09	0.93
Education level of household head[HH]	−0.103	0.130	−0.79	0.43
Number of extension meetings attended[HH]	0.251*	0.139	1.80	0.07
Importance of livestock income[HH]	−0.180	0.324	−0.56	0.58
Total members[HH]	−0.001	0.001	−1.08	0.28
Age of water project[CWP]	−0.004	0.020	−0.19	0.85
Whether CWP expanded in last 5yrs[CWP]	−1.073***	0.316	−3.40	0.00
CWP rotates during wet season[CWP]	−0.363	0.388	−0.93	0.35
Area of water project[CWP]	−0.006	0.024	−0.24	0.81
Total number of penalties for tampering[CWP]	0.437**	0.181	2.41	0.02
Total number of membership rules[CWP]	0.028	0.399	0.07	0.94
Constant	−0.890	1.353	−0.66	0.51
Log likelihood				−97.80
Pseudo R-squared				0.10
Number of observations				193

*** Statistical significance indicated at the 0.01 level.
** Statistical significance indicated at the 0.05 level.
* Statistical significance indicated at the 0.10 level.
HH/CWP Indicates the whether the variable is at the household or community level.

Table 4
Logistic regression of the likelihood of past experimentation with a new seed variety and determinants.

Experimented with new seed variety in the past	Coef.	Std. Err	z	P > |z|
Coefficient of variation of water flow[HH]	2.296**	0.971	2.36	0.02
Total income[HH]	0.000**	0.000	−2.17	0.03
Age of household head[HH]	0.001	0.011	0.11	0.91
Education level of household head[HH]	0.152	0.132	1.15	0.25
Number of extension meetings attended[HH]	0.079	0.158	0.5	0.62
Importance of livestock income[HH]	0.227	0.389	0.58	0.56
Total members[HH]	0.000	0.002	0.1	0.92
Age of water project[CWP]	−0.024	0.017	−1.45	0.15
Whether CWP expanded in last 5yrs[CWP]	0.278	0.481	0.58	0.56
CWP rotates during wet season[CWP]	−1.269***	0.466	−2.72	0.01
Area of water project[CWP]	0.037**	0.018	2.01	0.04
Total number of penalties for tampering[CWP]	0.373*	0.226	1.65	0.10
Total number of membership rules[CWP]	−0.965***	0.383	−2.52	0.01
Constant	1.951	1.756	1.11	0.27
Log likelihood				−116.12
Pseudo R-squared				0.12
Number of observations				194

*** Statistical significance indicated at the 0.01 level.
** Statistical significance indicated at the 0.05 level.
* Statistical significance indicated at the 0.10 level.
HH/CWP Indicates the whether the variable is at the household or community level.

different seed varieties in the past five years. This suggests that households currently with poor reliability of water delivery similarly experienced poor delivery in the past, prompting decisions to experiment with different seed varieties to help cope with variable conditions. This relationship helps to identify a potential inertia that exists in the study area: unreliable water delivery may be chronic for some households and this may result in ongoing seed experimentation by households as they seek varieties capable of securing an adequate harvest. Our independent group t-test in which we inspected seed adoption within the past five years also supports this idea that seed experimentation is an action taken by smallholders to confront water insecurity. Smallholders that adopted shorter maturing varieties experienced significantly drier conditions during the previous five years than those adopting late maturing varieties, thus highlighting an adaptive action taken by smallholders when confronted with challenging growing conditions.

6.2. Explaining seed adoption through other household-level pathways

Aside from water variability, Table 3 and 4 each revealed only one additional household-level driver of seed experimentation. In terms of future experimentation, a positive association was found with attendance at meetings with extension officers, and in terms of past experimentation, a positive, though small, association was found with total income.

Both of these relationships are in the direction hypothesized in Table 1. In the case of exposure to extension officers, the relationship suggests that contact with new ideas will increase farmer willingness to experiment with different seed varieties. This relationship is supported by studies such as Rahm and Huffman (1984), Kassie, Jaleta, Shiferaw, Mmbando, and Mekuria (2013), and McCord et al. (2015). In terms of income, the identified relationship agrees with investigations such as Somda et al. (2002), Pannell et al. (2006), and Knowler and Bradshaw (2007), which suggest that some financial security is needed before farmers experiment with different on-farm techniques. In coupling these findings with the community-level forces, which we discuss next, as well as the influence of household-level water variability, it is clear that farmer adaptation is interwoven into a complex and nested assemblage of contextual drivers.

6.3. The role of water governance and collective action in smallholder adaptation

Concerning the relationship of community-level variables to smallholder adaptation, we hypothesized that on-farm practices would most likely be adjusted if CWP governance reflected an inability to overcome collective action dilemmas. Smallholders experiencing appropriation and/or provisioning failures – or sensing impending failures – would be more likely to employ their own adaptation strategies given a need to "go it alone" as the CWP struggles to provide the services expected by members.

The goal of any user group managing a common pool resource is to instill collective action as a social norm among the membership. Crawford and Ostrom (2000) described norms as prescriptions held by individuals of what must, may not, and may be permitted. And while norms are important in overcoming social dilemmas, rules are also needed to back up these norms. For instance, members who trust one another and believe that all users within a CWP are entitled to equal shares of water are better positioned to overcome social dilemmas. Yet, opportunistic members may be willing to free ride on labor provisioning responsibilities or ignore certain water use restrictions. As a result, rules are needed to indicate member responsibilities and to ensure that malfeasance, such as tampering with pipe distribution infrastructure, will be accompanied with sanctions.

The results of the logistic regressions seeking to understand community-level predictors of smallholder adaptation allude to this blending of norms and rules in overcoming social dilemmas. First, consider the logistic regression seeking to understand future adoption of different seed varieties. In CWPs that had expanded their membership within the last five years, there was a negative association with seed adoption, signifying that new seed adoption was less likely when members had recently been added. We had anticipated the opposite: that the presence of newer members would act as a strain on trust and encourage members to seek out their own adaptation strategies. But what we may be observing is recognition by the membership and those tasked with governing the CWP that norms of trust and reciprocity are already strong enough to counter the addition of opportunistic water users. Thus, the CWP is adding new members because it is confident that it will be able to maintain collective action as a norm among its membership. Additionally, CWPs appear to view these norms as sufficiently

effective that members need not be burdened with onerous penalties for infrastructure infractions, as exhibited by the positive relationship between adaptation and sanctions (i.e., smallholder adaptation decreases alongside a decrease in the number of penalties for pipe tampering). While this relationship opposes what we had initially hypothesized, it does fit a narrative that smallholders in CWPs with social norms sufficient for overcoming social dilemmas will feel less pressure to alter their farming practices.

In terms of previous seed adoption, we again found a positive relationship between smallholder adaptation and the total number of penalties for infrastructure infractions. However, this regression also returned a negative relationship between total membership rules and seed adoption, where seed adoption decreased as the number of membership rules increased. This association is consistent with what we had initially hypothesized, and suggests that preselecting for rule-abiding, trustworthy members – as is true when CWPs impose a large number of criteria to be met in becoming a new member – may diminish the need for complicated, overly burdensome sanctions for water misuse. Thus, this blending of social norms and rules guarding against opportunistic individuals appears to have diminished the need for past seed experimentation as members remained confident in their user group's ability to overcome collective action dilemmas.

This model also suggested that within CWPs where water had been rotated among the membership during the wet season, which we used as an indicator of particularly large membership sizes, smallholders were less likely to have experimented with different seed varieties. This countered our initial hypothesis, but fits the narrative described in the previous paragraph: if membership rules are selecting for rule-compliant members who are good stewards of the resource and the infrastructure, then fostering trust among the membership, no matter how large, may not be an issue. What is interesting, however, is that the area of the CWP was positively associated with past farmer seed experimentation. This was consistent with our initial hypothesis, which we supported by arguing that collective action will be difficult to achieve if smallholders infrequently interact. With these limited interactions, there will be less opportunities to build trust, and members may sense a need to adopt their own adaptation strategies to counter any governance failures. Therefore, while the membership rules may be selecting for ideal water users that are receptive to trust building even as a large group, if the users are dispersed and infrequently interact, as would be likely in a CWP covering a large spatial extent, they are unable to build the social bonds needed to overcome collective action dilemmas. In other words, the simple presence of a large group of members receptive to the idea of building trust is insufficient; these members must interact for trust to take hold. Smallholders occupying expansive CWPs may recognize this shortcoming among the membership, leading them to question the viability of their water governance regime and alter their on-farm practices.

6.4. Recourse opportunities to shape water security and adaptation

We have argued that governance arrangements, which are typically crafted by CWP management committees, foster opportunities for collective action and in turn influence smallholder adaptation. Yet, the ability of local-level users to participate in water governance – a trait featured in Ostrom's design principles – means that they are not idle observers to governance decisions and the outcomes produced by these decisions. Further, the capacity to share information with other users, including resource managers, effects the ability of users to solve provisioning and appropriation dilemmas (Janssen et al., 2015). In this final subsection, we illustrate recourse opportunities for smallholders in response to management decisions and consider how this may influence adaptation.

Analysis of the CWP bylaws and constitutions revealed that nearly 80% of CWPs contained language formally stating that their management committees needed to consist of representatives from each of the major distribution lines, branches, zones, etc. within the CWP. These representatives serve on the management committee and are responsible for reporting concerns of poor flow, pipe damage, and other grievances from their constituents to the executive committee. Therefore, a communication mechanism exists, at least in theory, between individual CWP members and those responsible for making management decisions. A mechanism also exists for replacing poorly performing management personnel: nearly all management positions have defined term lengths allowing CWP members to remove an individual at the end of their term. For example, if a branch representative consistently fails to report a broken water distribution pipe and the ensuing complaints of poor water flow, the CWP membership would be able to elect a new representative for this branch at the conclusion of the term. Term lengths are set at two years in the majority of CWPs (85%). Community water projects do diverge, however, in their re-election procedures and their usage of term limits: a nearly even split exists between CWPs that allow management personnel to seek re-election indefinitely at the end of each term and those that limit the number of terms an individual may pursue.

The term length and re-election procedures are key elements in understanding communication between water managers and users, as well as the recourse opportunities for users dissatisfied with such items as poor water delivery and member non-compliance with rules. Analysis of the formal rules revealed that term lengths are typically short and that many CWPs impose a restriction on the number of terms served, which suggests that consistent, effective representation is necessary if an individual hopes to retain their position on the CWP management committee. Thus, evidence exists that smallholders have a channel through which to communicate with the CWP management committee and a mechanism to hold these decision-makers accountable if they are deemed to be ineffective stewards of the water resource and irrigation infrastructure. Further investigation is needed to establish the effectiveness of this recourse option.

7. Conclusion

This study investigated adaptation in smallholder dominated semi-arid irrigated agroecosystems. In these environments, smallholders depend on irrigation to mitigate periodic dry spells and drought events and enable agricultural production in downstream areas that do not receive sufficient rainfall in some years for reliable production. Our research contributes to existing work on adaptation in smallholder systems by considering the interplay between institutional dynamics and household-level decision-making in small scale irrigation systems affected by chronic drought. The role of resource governance in farmer adaptation is especially critical in locations where climate change is anticipated to have significant impacts and where a large portion of households are reliant on subsistence agriculture for their livelihoods. We demonstrated that diminished capacity to irrigate at the household-level is associated with greater willingness to try seed varieties with different maturation periods. This supports the notion that smallholders will engage in adaptive behaviors if water shortages create a sense that on-farm practices must be adjusted. However, the role of community-level water governance also plays a role in the potential for household-level adaptation. In particular, smallholder adaptation is dependent on the ability of users to build trust in each other, as well as the effectiveness of water institutions

in confronting collective action challenges. This paper suggests that adaptation research should not simply consider households as independent actors but rather the potential for community-level governance to affect smallholder adaptation. Future work exploring decision-making in semi-arid agroecosystems will benefit from investigating this interplay between resource governance, water availability, and smallholder adaptation.

Conflict of interest statement

We are unaware of any conflicts of interest concerning the authors and the research presented herein.

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